ENERGY AND EXERGY ANALYSIS OF FCC UNIT

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ABSTRACT The energy and exergy balances were effectively calculated by the three-section model and the two-box method on the basis of field data of the FCC unit. The results show that the net energy consumption of the FCC unit is 2197.60MJ/t. Simultaneously, the efficiency of the exergy of the conversion section is rather poor, and the energy losses of the recovery section are much higher. The losses of the energy and exergy of regenerator are greatest in the conversion section. It means that it is not enough only to reduce the heat losses of the flue gas, the exergy losses of the process is also important to the reduction of the coke formation. In conclusion, the calculations show that conversion and recovery sections have more potential to the reduction of energy consumption. It indicated that the key factors are to reduce the energy consumption of the regenerator, optimize the heat exchanging system and utilize the low temperature heat.

KEYWORDS: catalytic cracking; energy consumption; exergy analysis

1. INTRODUCTION

Catalytic cracking is one of the most important petroleum refining processes. The most significant characteristic of the cracking process is its flexibility in treating the variety of feedstock available from the crude currently being refined, which becomes increasingly important, as refiners are obliged to resort to heavier crude containing refractory or poisonous constituents, due to shortages and to the high price of the more desirable crude. Many technologies are applied to the FCC processes for raising the operating efficiency, innovated decreasing the energy consumption, producing high quality products, and obtaining more remarkable economic benefits. However, the flexibility of the FCC process is negatively weakened by the excessive energy consumption. Thus, the improvement of the efficiency of the energy utilization has been the subject of investigations designed to optimize the fundamental problems in engineering and processes. The great majority of such investigations has been conducted by petroleum companies and held confidential in order to improve the economic benefits. It suggested that the majority of the energy and exergy analysis is purely "applied". Because of the highly "applied" nature of this work in the field, understanding of the various phenomena involved in FCC process is far from complete. In order to understand the effect of energy consumption in FCC process, two kinds of analysis methods of energy and exergy are usually employed in the cracking process.

(1) three-section model[1]. The conversion and transport of energy, technology utilization and energy recovery, i.e., three-sectionm odel of energy analysis is adopted according to the clue of energy utilization and evolution.

(2) two-box method[2]. The gray-box and black-box methods are applied to energy analysis in terms of different systems and equipment involved. The degree of energy utilization of the systems and equipment is available by this method.

The paper aims to study the energy utilization level of the catalytic cracking process employing three-section model and gray-box or black-box methods.

2. EXPERIMENTAL

All field data used in this paper were collected with locale unit. On the basis of field data of the FCC unit, the energy and exergy balances were calculated by the three-section model and the two-box method.

3. ENERGY AND EXERGY BALANCE ANALYSIS

The overall evaluation of the energy consumption according to three-section model is shown in table 1. The net energy consumption and primary energy consumption of the FCC unit amount

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to 2197.60 and 2425.43MJ/t, respectively. The conversion and recovery section suffer from high-energy loss and has much potential to improve. The energy and exergy balance analysis is conducted employing gray-box method according to three-section model and the evaluation results of the three-section are shown in table 2[3].

The energy conversion section consists of regenerator (included flue gas energy recovery system), main air blower, gas compressor and pumps. The regenerator suffers great energy and exergy losses with the respective loss coefficient of 21.0% and 41.7%. The energy and exergy analysis of the regenerator is calculated according to the gray-box model and results are shown in table 3. The utilization efficiency and losses of the energy and exergy are evaluated.

The heat exchanger and condenser are made up of the energy recovery section. The cooling energy and exergy are abandoned and puts on the loss item, so only the total cooling energy and exergy are calculated. A portion of energy and exergy of the heat exchanger are lost in the recovery section. The energy and exergy analysis of the heat exchanger is carried out employing black-box model and the results are shown in table 4.

4. DISCUSSION

4.1 Conversion section

It can be seen from table 2 and 3 that the regenerator and recovery system suffer the greatest energy and exergy losses and supply a low energy utilization efficiency of 77.18.The recovery heat energy of the flue gas should be paid attention due to the high energy losses coefficient of 16.80 . Simultaneously the results of the exergy analysis show that the process exergy loss coefficient of 35.16 is much higher than the exhausting flue gas exergy loss coefficient of 6.11 . It means that it is not enough only to reduce the heat losses of the flue gas, the reduction of the exergy losses of the process is more important. The process exergy losses, which consists of the irreversible burning loss of the coke and the heat transfer loss, becomes the weak section of the energy utilization and also the potential aspect to the reduction of energy consumption of the conversion section. The key to reduction of the exergy losses of the regenerative process lies in suppressing coke yield so as to decrease exergy loss of the burning process.

The pressure and heat energy of the flue gas should be recovered in order to improve energy utilization efficiency of the regenerator. The pressure energy of the flue gas can be recovered by the flue gas expander, while the utilization degree of the sensible heat of the flue gas depend on its exhaust temperature. The flue gas expander generated horsepower directly going into the electrical network. In this unit the recovery power ratio (the power ratio of flue gas expander to the air blower) of 73% is lower. The design capacity of the flue gas expander is smaller to partial bypass of flue gas and the heat loss of the flue gas pipelines is greater. Therefore the recovery power ratio can be increased to 114% if pressure energy of flue gas is sufficiently utilized. The expander has a horsepower recovery potential exceeding the requirements of the air blower. In this way, the work recovered by the flue gas expander not only maintains the regular operation of the air blower, but also generate a part of electricity.

The waste heat boiler is used to produce the middle pressure steam of 3.6MPa, and the exhaust temperature of flue gas is at 256, of which energy can be farther recovered. Furthermore, only 65% flue gas flows into the waste heat boiler. It means that 35% of flue gas is exhausted with high temperature of 526. In a word, it is necessary to reduce the direct emission and recover the heat of flue gas more efficiently.

The efficiency of pumps is generally low, 71% of pumps operated with the efficiency below 50%. It indicates that it is worthy to improve the efficiency of the pumps. The application of new type high-efficiency pump or electric machine with frequency converter may be a good choice to improve the drive conversion efficiency. By so doing, electricity energy can be saved.

Although, the power losses of conversion process was lower, but the value high to the other formal energy, hence it cannot be ignored.

4.2 Technology utility section

The total supplied energy of the technology utility section is 2740.76MJ/t, has higher level. Of special is that the proportion of the recovery cycle energy and exergy is low, with 22.5 and 12.7 of the total supplied energy, respectively.

The thermodynamic energy and exergy consumption is that the total supplied energy and exergy transform to the part of the products , with the respective ratio of 19.0 and 27.4. It indicates that the decline of the total supplied energy is also a potential route to improve the energy and exergy consumption.

In technology utility section, exergy losses coefficient of heat dissipated is 3.64 , exergy losses of the process is 18.54 . It means that the reaction and fractionation processes contribute very much to the exergy losses.

The energy utility level of the main fractionation tower has quite influence on the total energy consumption. The exergy loss of the fractionation tower is mostly derived of heat transfer. Therefore heat removal by the top reflux should be minimized while more heat can be removed by hot mid-section reflux and slurry oil reflux if the product quality and yields are ensured. Additionally it is a method to minimize the temperature difference between inlet and outlet tower flows of the reflux.

4.3 Energy recovery section

The ratio of energy and exergy recovery were 54.43 and 45.97, respectively. The cooling energy and exergy losses were 38.39 and 29.56 accordingly in the section supplied energy.

The cooling losses of the whole unit constitutes 35.6 of the net energy consumption and becomes the chief part of the energy consumption. The crux of reducing the cooling(heat rejection) loss rests with the utilization of low temperature heat owing to the most heat below

The data in table 4 indicate exergy losses coefficient of the heat exchanger network reaches 27.69%. The high temperature difference of heat transfer brings about the great exergy losses. The exergy losses of heat transfer can be inhibited by the optimization of the heat exchanger system.

5. APPROACH OF ENERGY SAVING

The energy conversion and recovery become the weak section of the energy utilization. But technology utility section is core of energy utility. It determines the amount of energy available from recovery and conversion sections. As a result, to minimize the total supplied energy of the technology utility section is the first consideration, subsequently the recovery and conversion sections are considered.

(1) Reducing total supplied energy of the utility section

Introducing advanced technology, optimum catalysts and effective additives are front problems to reducing the total supplied energy of the technology utility section. Besides little heat of steam is utilized in the technology section. The introduction of advanced technical measurements may be a choice to decrease the amount of steam used. For example the dry-gas prelifting technology can not only save energy but also cut down dry gas and coke yield. In addition, appropriate low temperature heat may be used to supply instead of the accompanying steam.

The throttle losses of the exit valve can be reduced through the selection of proper pumps. For the pump with frequent flux change, the variable-frequency electric machine is a good substitute for elevation of pump efficiency and decline of electrical energy.

(2) The optimization of heat exchanger network is an effective way to decrease heat transfer exergy losses and improving the energy recovery ratio. In the first step, the heat exchangers with the temperature difference upwards of 30 should be eliminated. Secondly, it is worth while to enhance the heat preservation of high-temperature position. Finally, the integrated utilization of low-temperature heat becomes more and more important with the deepening of the idea of energy savings. A great deal of low-temperature heat supplied with catalytic cracking process can be made use of heating medium of other units or devices, such as preheating water supply and living heating in winter, etc. Next low temperature heat may be considered to upgrading utility, which might face the lower efficiency and higher investment.

(3) The energy utilization efficiency of the regenerator lies on the recovery and utilization of flue gas due to the adoption of the complete combustion technique. Hereby, it is important for the regenerator and energy recovery system to maintain the flue gas expander operates in a perfect performance. In addition, the heat of flue gas should be recovered sufficiently by the waste heat boiler. In a word, it is very significant for the energy saving to maintain the long-cycle, full-loaded, and high-efficient running of the flue gas expander and the waste heat boiler.

6. CONCLUSIONS

The measures of energy saving must be determined in the opinion of energy and exergy balance analysis. For the catalytic cracking unit with the flue gas expander and waste heat boiler, the recommended measurements of energy saving are as follows:

(1) Improving the recovery and utility ratio of the flue gas expander and reducing exhausting temperature of the waste heat boiler. Maintaining the long-cycle, full-loaded, and high-efficient running of the flue gas expander and the waste heat boiler.

(2) Optimizing the heat-exchanging network to reduce temperature difference of heat transfer of the heat exchangers.

(3) Strengthening the integrated utilization of low temperature heat.

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Table 1 the recapitulation statement of energy and exergy analysis using of three-section model

Item	Energy	Exergy
Net energy(exergy) consumption MJ/t	2197.60	2221.96
Primary energy consumption MJ/t	2425.43	
Total supplied energy (exergy) of utilization section MJ/t	2740.76	1455.72
Conversion efficiency	78.30	56.57
Energy utilization efficiency	93.32	77.82
Recovery rate	54.43	45.97
Total ejected energy and exergy MJ/t	1639.57	531.93
Total process exergy losses MJ/t		1255.71
Losses MJ/t :		
Conversion section	534.42	1067.11
Utilization section	182.94	322.84
Recovery section	927.70	396.59

Table 2 The recapitulation statement of gray-box of "three-section" model

Item			energy analysis		exergy analysis	
			Energy MJ/t	Energy loss coefficient %	Exergy MJ/t	Energy .loss coefficient %
Energy conversion section	Input	Regenerator	2342.06		2245.29	
		Main air blower	139.42		139.42	
		Gas compressor	42.00		50.42	
		Pump	21.98		21.98	
		Sum	2545.46		2457.11	
	Output	Regenerator	1807.64		1220.02	
		Main air blower	135.39		125.69	
		Gas compressor	39.20		33.38	
		Pump	10.91		10.91	
		Sum	1993.14		1390.00	
	Losses	Regenerator	534.42	21.00	1025.27	41.73
		Main air blower	4.03	0.16	13.73	0.56
		Gas compressor	2.80	0.11	17.04	0.69
		Pump	11.07	0.43	11.07	0.45
		Sum	552.32	21.70	1067.11	43.43
Utilization section	Supplied energy		2740.76		1455.72	
	Thermodynamic energy and exergy consumption		522.09		398.93	
	Exergy Losses	Reactor			135.08	9.28
		Main fractionator			91.42	6.28
		Other units			43.39	2.98
		Sum			269.89	18.54
	Losses of rejection of heat		182.94	6.67	52.95	3.64
	Needed recovery energy		2035.72		733.96	
Reco	Recovery cycle		616.63		184.66	
	Recovery output		491.39		152.71	
	Losses	Heat losses	63.77	3.13	19.39	2.64
		Cooling	781.51	38.39	216.96	29.56
		Other	82.42	4.05	5.75	0.78
		Sum	927.70	45.57	242.10	32.98

Exergy losses	Condenser and heat exchanger	124.18	16.92
	Other	30.31	4.13
	Sum	154.49	21.05

Table 3 The results of the regenerator and energy recovery system

Item	Energy MJ/t	Energy loss coefficient	Exergy MJ/t	Exergy loss coefficient
Supplied energy(exergy)	2342.06		2245.29	
Useful energy(exergy)	1807.64		1220.02	
Energy utilization efficiency	77.18			
Exergy utilization efficiency			54.34	
Exhaust flue gas	393.44	16.80	137.22	6.11
CO chemical energy	8.90	0.38	8.90	0.40
Heat losses	127.04	5.42	88.36	3.93
Other	5.04	0.22	1.44	0.06
Process exergy losses			789.35	35.16
Total	534.42	22.82	1025.27	45.66

Table 4 The black-box analysis results of heat exchanger

Energy analysis			Exergy analysis		
Item	Energy MJ/t	Energy loss coefficient	Item	Exergy MJ/t	Exergy loss coefficient
Supplied energy	871.77		Supplied exergy	381.60	
Recovery energy	840.15		Recovery exergy	265.38	
Heat losses	31.62	3.63	Exergy losses of heat	10.55	2.76
			Process exergy losses	105.67	27.69
Total energy losses	31.62	3.63	Total exergy losses	116.22	30.45